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Product-Service Systems across Life Cycle

An approach based on improved grey model for predicting maintenance time of IPS^2

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Abstract

Maintenance service is the most important part in industrial product-service system (iPSS). To enhance the proactiveness of maintenance service, the failure time of product need to be predicted. This study provides insight into how the maintenance time can be predicted accurately for the service decision-making of IPSS based on the historical failure time data, avoiding the dependence on mechanical condition monitoring. An improved grey prediction model is introduced to obtain a predictive interval of maintenance service time which is used as basis for making a decision of proactive maintenance service. The method is applied in an instance of maintenance service for agricultural machinery. In three examples of different types of agricultural machinery, the predicted intervals of maintenance time are given and the fitted values have high accordance with the real ones. The result shows that this approach can be used effectively to predict production failure time. Moreover, the output results of this approach can provide the necessary support to make a decision for proactive maintenance service without the dependence on mechanical condition monitoring in a reliable way.

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Keywords: maintenance service; IPSS; time prediction; grey theory

1. Introduction

The product-service system represents a competitive opportunity for many companies as they seek to reduce consumption by providing personalized products and services [1]. Maintenance services are especially concerned, which is the main and the most frequent part of machinery and equipment industry in iPSS. In the traditional breakdown maintenance pattern, the service is prepared after the product failure occurs and the requirement of service is confirmed. Thus, the delay of service delivery is brought out in the procedures of confirmation, scheduling and removing which is unacceptable when the service requirement is urgent.

With accumulation of tasks and increase of service range, the conventional maintenance strategy is not adapted to the demands of present maintenance service, which is a crucial part of the product service system across life cycle. By contrast, the strategy of proactive maintenance has the goal of avoiding system breakdowns as much as possible by using historical data and statistical computations to put into direct relation the time with the probability of system breakdown.

Maintenance prediction is the most important basis of the proactive maintenance strategy. In the field of predictive maintenance, now popular traditional failure prediction methods are mainly focused on how to use the condition monitoring data of several key parts to make prediction [2,3]. Besides, most of the researches are concerned about the maintenance cost rather than the maintenance time [4,5]. The issue of making short term time prediction without the dependence on mechanical condition monitoring is still remaining.

This study focuses on making use of the historical maintenance records rather than the monitoring data collected from sensors to predict the time when a failure would occur on a product in iPSS based on the grey system theory. There are some common methods in the field of quantitative forecasting, but some of them are not applicable in the scene of this study where the amount of available data is little, the known information is rare and the occurrence of failure is irregular.

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Artificial Neural Network (ANN) as well as some statistics-based methods cannot be implemented without sufficient data. Markov method has the limitation of non-aftereffect prerequisite. By contrast, the grey system theory can build a forecasting model with a few samples and irregular data and doesn't need any assumptions [6].

In this paper, a maintenance time prediction approach based on an improved grey model is proposed to solve the problem and relevant case study is given.

The rest of this paper is structured as follows. In Section 2, the problem is stated and modeled. Section 3 is devoted to the description of our methodology. The result is shown in Section 4. Finally, the conclusion is stated in Section 5.

2. Problem statement

2.1. Predictive maintenance for agricultural machinery

The problem to be solved in this study is the prediction on maintenance time for agricultural machinery in iPSS. In this study, we consider a realistic situation where the available information of each product is poor and the service tasks are always urgent and passive. It is founded in China's agricultural equipment manufacturing where the predictive maintenance problems are pressing to be resolved and the iPSS of manufacturers need to be improved.

In term of each product, the customer makes a maintenance service requirement through the form of telephone call to the service department of the manufacturer. Once a service requirement is received, the dispatcher of service department sends an order to the service staff. The service staff goes to the site and implements maintenance service for the product as soon as possible. For the purpose of satisfying numerous requirements in a quick, reasonable and economical way, the dispatcher need to use the strategy of proactive maintenance, which needs a prediction of maintenance time. In this study, we regard the failure time of product as the time when the maintenance service is needed.

In the maintenance service for production equipment, the timeliness is the most important consideration because it directly relates to the customers' benefit, especially in agricultural machinery industry, where customers' reviews have a great impact on the market share.

The maintenance service discussed in this study has the features as follows:

- Importance of timeliness.
- Rare application of sensors.
- Varying amount of available historical data depending on the usage time of each product.

As is stated in Section 1, the existing researches are mainly focused on the visible service cost and the utilization of sensors. Researches concerned about the features mentioned above is still lacked, so this study aims to solve relevant problem based on the grey system theory.

The grey system theory focuses on the study of the grey system, which is between the white system with all information known and the black system with all information unknown [7]. The grey system theory thinks that, for a given grey system, there is potential information contained in the time series of data [8], which looks unordered, though. The develop law can be extracted by processing raw data and establishing the *grey model* (GM), which is the core content of grey system theory. Since the foundation of grey system theory in 1982, the grey prediction model is applied to solve many research and engineering problems, especially in the field of failure prediction [6,9,10,11].

Each product is a typical grey system with both unknown and known information. For each product in iPSS, the occurrences of failure are determined by many aspects of factors, such as the current condition of product, the operation environment, the manipulation of users and so on, and there are large number of factors in each aspect. Most of these factors are not obtained for us. On the other hand, the failure time records of every product are available. With the existing records, a predictive value of time when the failure will occur the next time can be given by grey prediction model.

2.2. Modeling of maintenance prediction based on GM

The maintenance time prediction approach is described as follows and shown in Fig.1.

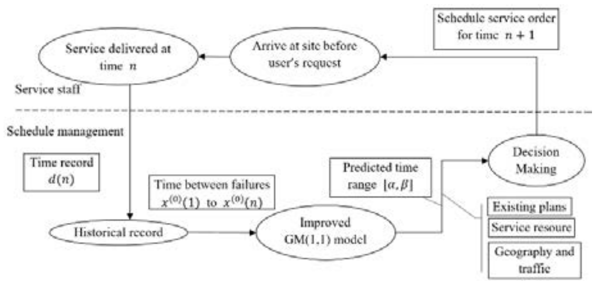

Fig. 1.Model of maintenance time prediction for iPSS.

Firstly, after a service action is delivered at time n, an actual value of the fault occurrence time of one product is collected and recorded into historical record.

Next, in order to predict when this product is going to break down and further make a service decision in advance, we need to extract the data of time between failures from the maintenance record of this product. Assume that time between failures among time $n-1$ and time n is noted as $x^{(0)}(n)$. Obtain data $x^{(0)}(1), \ldots, x^{(0)}(n)$ and the amount is n, a parameter determined by the scale of the historical record.

The extracted data $x^{(0)}(1), \ldots, x^{(0)}(n)$ compose a data sequence $X^{(0)}$. Aiming at the random oscillation characteristic of the raw sequence, an improved grey model is applied [12]. Use $X^{(0)}$ as the input of the improved GM(1,1). The predictive value and the accuracy of this prediction, namely the average relative error $\bar{\varepsilon}$, are obtained. With these results, a time range can be given. The time range is the final conclusion of the prediction method based on the improved GM(1,1) model and means that the next failure of this product will occur in this interval of time.

Then, the prediction result, namely the time range, is submitted to the schedule procedure. The dispatcher takes the predictive time range, service source, geography and traffic and existing plans into consideration comprehensively and finally give a detailed service order to the service staff. According to